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Sonar Estimation of Chinook and Fall Chum Salmon Passage in the Yukon River near Eagle, Alaska, 2011

by

Elizabeth A. Smith

and

Roger D. Dunbar

September 2012

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_{2}$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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by
Elizabeth A. Smith
and
Roger D. Dunbar
Alaska Department of Fish and Game, Division of Commercial Fisheries, Fairbanks

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

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Elizabeth A. Smith and Roger D. Dunbar
Alaska Department of Fish and Game, Division of Commercial Fisheries,
1300 College Road, Fairbanks, AK 99701, USA

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ABSTRACT

Dual frequency identification sonar and split-beam sonar equipment were used to estimate Chinook salmon *Oncorhynchus tshawytscha* and fall chum salmon *Oncorhynchus keta* passage in the Yukon River near Eagle, Alaska from July 5 to October 6, 2011. A total of 51,271 Chinook salmon were estimated to have passed the sonar site between July 5 and August 12. The midpoint of the Chinook salmon run occurred on July 24, which was one day early relative to the historical mean date of July 25. An estimated 212,162 chum salmon passed between August 13 and October 6. The sonar-estimated passage of chum salmon was subsequently expanded to a total passage estimate of 224,355 to include fish that may have passed after operations ceased. The midpoint of the chum salmon run, when the expansion is included, occurred on September 20, which was 2 days early relative to the historical mean date of September 22. Subtracting the preliminary subsistence catch upstream of the sonar site resulted in an estimated border passage of 50,888 Chinook salmon, and 211,930 chum salmon. A drift gillnet sample fishery was conducted to collect age, sex, length, and genetic information. Species composition was also recorded to determine when the Chinook salmon run ended and the fall chum salmon run began. Both sonar systems functioned well with minimal interruptions to operation. Range of ensonification was considered adequate for most fish that migrated upstream. A continued long-term hydroacoustic enumeration project for Chinook and chum salmon near the United States/Canada border will help fishery managers meet conservation and management commitments made by both countries under the Yukon River Salmon Agreement.

Key words: Alaska, Yukon River, Eagle, Chinook and chum salmon, *Oncorhynchus*, DIDSON, split-beam sonar, hydroacoustics.

INTRODUCTION

The Yukon River is the largest river in Alaska, spanning 3,700 km. It flows northwesterly from its origin in northwestern British Columbia through the Yukon Territory and Central Alaska to its mouth at the Bering Sea. Commercial and subsistence fisheries harvest salmon throughout most of the drainage. These fisheries are critical to the way of life and economy of people in dozens of communities along the river, in many instances providing the largest single source of food or income. Fisheries management on the Yukon River is complex and difficult because of the number, diversity, and geographic range of fish stocks and user groups. Information upon which to base management decisions comes from several sources, each of which has unique strengths and weaknesses. Gillnet test fisheries provide inseason indices of run strength, but interpretation of these data is confounded by gillnet selectivity. In addition, the functional relationship between test fishery catch and abundance is poorly defined. Mark–recapture projects provide estimates of total abundance, but the information is typically not timely enough to make day-to-day management decisions. Sonar provides timely estimates of abundance, but is limited in its ability to identify fish to species level.

Alaska is obligated to manage Yukon River salmon stocks according to precautionary, abundance–based harvest–sharing principles set by the *Yukon River Salmon Agreement* (Yukon River Panel 2004). The goal of bilateral, coordinated management of Chinook *Oncorhynchus tshawytscha* and chum *Oncorhynchus keta* salmon stocks is to meet negotiated escapement goals and also provide for subsistence and commercial harvests of surplus in both the United States and Canada. Timely estimates of abundance not only help managers adjust harvest inseason, they are crucial for postseason analysis to determine whether treaty obligations were met. The Canadian Department of Fisheries and Oceans (DFO) provided estimates of mainstem salmon passage through the U.S./Canada border using mark–recapture techniques from 1980 to 2008.

Because of the highly turbid water of the Yukon River, and the width of the mainstem (approximately 400 m across at the study site), daily passage estimation methods that rely on visual observation, such as counting towers and weirs, are not feasible. Split-beam sonar technology has been used successfully by the Alaska Department of Fish and Game (ADF&G) to produce daily inseason estimates of salmon passage in turbid rivers, including the lower Yukon River at Pilot Station (Carroll and McIntosh 2008) and the Kenai River (Miller and Burwen 2010). Dual frequency identification sonar[1] (DIDSON) are used at several sites, including the Aniak River (McEwen 2010) and the Sheenjek River (Dunbar 2010) to give daily passage estimates where bottom profile and river width are appropriate for the wider beam angle and shorter range capabilities of this technology.

In 1992, ADF&G initiated a project near Eagle, Alaska (Figure 1) to examine the feasibility of using split-beam sonar to estimate the number of salmon migrating across the U.S./Canada border (Johnston et al. 1993; Huttunen and Skvorc 1994). This project was the first documented use of split-beam sonar in a riverine environment and, over the 3-year duration of the study, a number of problems were identified. Phase corruption was observed and was probably exacerbated by the highly reflective river bottom (Konte et al. 1996). The errors in the phase measurement were believed to have resulted in overly restrictive echo angle thresholds causing the removal of echoes from fish that were physically within accepted detection regions. These and other equipment issues reflected the early state of split-beam development, most of which have since been addressed.

A recommendation that came out of these studies was to find a more appropriate site with smaller rocks and a uniform bottom profile (Johnston et al. 1993). Too many large rocks or obstructions in the profile can compromise fish detection by limiting how close to the bottom the hydroacoustic beam can be aimed. Similarly, an uneven bottom profile permits fish to pass undetected by the sonar.

In 2003, ADF&G carried out a study to identify a more suitable location to deploy hydroacoustic equipment to estimate salmon passage into Canada. A 45 km section of river from the DFO mark–recapture fish wheel project at White Rock, Yukon Territory to 19 km downriver from Eagle, Alaska was explored (Pfisterer and Huttunen 2004). This area was investigated because of its proximity to the DFO project and the U.S./Canada border. Desirable characteristics included: linear bottom profiles on both sides of the river without large obstructions; a single channel; available beach above water level for topside equipment; and sufficient current, i.e., areas without eddies or slack water where fish milling behavior can occur. A total of 21 river bottom profiling transects led to a narrowing of potential project locations to an area between 9 and 19 km downriver from the town of Eagle. The 2003 study identified the two most promising sonar deployment locations at Calico Bluff and Shade Creek. Though sonar was not deployed in 2003, the bottom profiles at the preferred sites indicated that it should be possible to estimate fish passage with a combination of split-beam sonar on the longer, linear left bank and DIDSON on the shorter, steeper right bank. ADF&G carried out a study over 2 weeks in 2004 to test sonar at the preferred sites. The two types of sonar were tested at Calico Bluff and the Shade Creek area and it was found that Six Mile Bend (11.5 km downriver from the town of Eagle and immediately upstream of Shade Creek) was the most ideal site (Carroll et al. 2007a).

In 2005, a full-scale sonar project was conducted from July 1 to August 13 to estimate Chinook salmon passage in the Yukon River at Six Mile Bend (Carroll et al. 2007b). As suggested, DIDSON was deployed on the right bank and split-beam sonar was deployed on the left bank.

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[1] Product brand names are included in this report for scientific completeness, but do not constitute product endorsement.

The project duration was extended in 2006 to provide an estimate of fall chum salmon passage. Split-beam and DIDSON technology have been used in subsequent years to estimate border passage for both Chinook and fall chum salmon.

STUDY AREA

The study area is a 2 km section of the mainstem Yukon River at Six Mile Bend, 11.5 km downriver from Eagle, Alaska (Figure 2). Some additional drift gillnet fishing occurs about 5 km downriver near Calico Bluff.

The Yukon River Basin is the fourth largest basin in North America with a drainage area of 857,300 km^2 and an average annual discharge of 6,400 m^3/s. Flows are highest in June, with greatest variability in flow occurring in May, after which discharge and the variability in discharge decline. The upper Yukon River is turbid and silty in the summer and fall with an estimated annual suspended sediment load at Eagle of 33,000,000 tons (Brabets et al. 2000).

Hungwitchin Native Corporation owns the majority of land in the study area above the ordinary mean high water mark. Permission was granted to operate a sonar project on Hungwitchin land at Six Mile Bend. A semi-permanent field camp consisting of 6 canvas tents on plywood platforms was constructed in 2005 on the left bank (64° 51’55.70” N 141° 04’43.62” W). An additional tent platform with a 12 ft x 15 ft Weatherport portable building was constructed on the left bank 1.3 km downriver from the camp (64°52’30.84” N 141°04’52.77” W) to house computer and sonar related equipment. A portable wooden shelter was used on the right bank to house topside sonar equipment, a wireless router, and a solar powered battery bank.

OBJECTIVES

The primary goals of this project in 2011 were to:

1. Estimate the daily passage, seasonal passage, and run timing of Chinook and fall chum salmon using fixed-location split-beam and DIDSON sonar.
2. Use drift gillnets to estimate the end of Chinook salmon run, and the beginning of the fall chum salmon run past the sonar site.
3. Collect a minimum of 160 Chinook salmon samples during each of 3 stratum throughout the season to characterize the age, sex and length (ASL) composition of Yukon River Chinook salmon passage, such that simultaneous 95% confidence intervals of age composition are no wider than 0.20 (α=0.05 and d=0.10).
4. Collect a minimum of 160 fall chum salmon samples during each of 4 stratum throughout the season to characterize the age, sex and length (ASL) composition of Yukon River fall chum salmon passage, such that simultaneous 95% confidence intervals of age composition are no wider than 0.20 (α=0.05 and d=0.10).
5. Collect Chinook and fall chum salmon tissue samples for genetic stock identification.
6. Collect daily climate and hydrologic measurements representative of the study area.

METHODS

HYDROACOUSTIC EQUIPMENT

A fixed-location, split-beam sonar developed by Kongsberg Simrad was used to estimate salmon passage on the left bank. Fish passage was monitored with a model EK60 digital echosounder, which included a general-purpose transceiver and a 2.5° x 10° 120 kHz transducer. ER60 data acquisition software installed on a laptop computer connected to the echosounder collected raw data for processing. Digital files created by the ER60 software were examined with the echogram viewer program Echotastic (Carl Pfisterer, Commercial Fisheries Biologist, Fairbanks, personal communication), to produce an estimate of fish passage.

The transducer was attached to two Hydroacoustic Technology Incorporated (HTI) model 662H single-axis rotators. Aiming was performed remotely using a HTI model 660 remote control unit that provides horizontal and vertical position readings.

A DIDSON long-range unit, manufactured by Sound Metrics Corporation, was deployed on the right bank. This sonar was operated at 1.2 MHz (high frequency option) for the 0 to 20 m range, and at 0.70 MHz (low frequency option) for the 20 to 40 m range, using 48 beams. Both the low and high frequency modes have a viewing angle of 29° x 14°. A 60 m cable carried power and data between the DIDSON unit in the water and a topside breakout box. A wireless router transferred data between the breakout box and a laptop computer on the opposite bank. Sampling was controlled by DIDSON software loaded on the laptop computer. All surface electronics were housed on shore in a small, wood frame shelter. Power for hydroacoustic equipment and computers was supplied separately on each bank with portable 2000 W generators running continuously.

SONAR DEPLOYMENT AND OPERATION

Several bottom profiling transects were made in 2005 to find a suitable specific location for sonar deployment on both banks. Specific sites were selected based on a profile consisting of a steady downward sloping gradient without large dips or obstructions that can hinder full acoustic beam coverage or detection of targets, sufficient current containing no eddies, and sufficient beach above water line to house topside sonar equipment. Each season, prior to transducer deployment, bottom profiles are checked to ensure the original sites remain acceptable for ensonification. Data was collected from 8 transects made from bank-to-bank using a boat-mounted Lowrance LCX-15 dual-frequency transducer (down-looking sonar) with a built-in Global Positioning System (GPS). A bottom profile was then generated using data files uploaded to a computer and plotted with Microsoft® Excel (Figure 3).

The split-beam sonar was deployed July 4 on the left bank, and was operational on July 5. The transducer and rotators were mounted on a freestanding frame constructed of aluminum pipe and deployed approximately 15 m from shore. The frame was secured with sandbags and the transducer height was adjusted by sliding a mounting bar up or down along riser pipes that extended above the water. The transducer was deployed at approximately 1.0 to 1.5 m depth and aimed perpendicular to the current along the natural substrate. The transducer was deployed at a location with consistent flow and no eddy or slack water.

An artificial acoustic target was used at various distances from the transducer during deployment to verify that the transducer aim was low enough to prevent salmon from passing undetected beneath the acoustic beam and to test target detection at different ranges. The target, an airtight 250 ml weighted plastic bottle tied with monofilament line, was drifted downstream along the river bottom and through the acoustic beam. Several drifts were made with the target in an attempt to pass it through as much of the counting range as possible. Proper aim for the split-beam system was verified with visual interpretation of an echogram on a computer screen, i.e. with visible, but not overpowering return of bottom signal appearing over the majority of the ensonified range.

The split-beam system was aimed to ensonify a range of approximately 2 to 150 m when counting Chinook salmon, and 2 to 75 m when counting chum salmon. Settings for data acquisition included: 256 µs transmit pulse lengths, 500 W power output, 5 pings per second at 150 m range, and 10 pings per second at 75 m range.

A portable tripod-style fish lead was constructed approximately 1.5 m downstream from the transducer to prevent fish passage inshore of the transducer and provide sufficient offshore distance for fish swimming upstream to be detected in the sonar beam. Sixteen freestanding lead sections constructed of two in diameter steel pipes connected with adjustable fittings to form tripods were used. Aluminum stringers, approximately 2.5 m long, were then attached horizontally to the upstream side of the tripods. The sections were finished with vertical lengths of aluminum conduit 3.8 cm apart. Lead sections were placed side by side in the water from shore to a distance of 5 m to 12 m beyond the transducer. The portability of this style of fish lead was important because of the gradual slope found on the left bank. As the water level rises and falls over the duration of the summer, the transducer and lead require frequent relocation to shallower or deeper water.

The DIDSON was deployed July 5 on the right bank, mounted on an aluminum frame and aimed using a manual crank-style rotator. Operators adjusted the aim by viewing the video image and relaying aiming instructions to a technician on the remote bank via handheld VHF radio. Proper aim was achieved when adequate bottom features appeared over the majority of the ensonified range (0 to 40 m).

A fish lead was constructed with 2 m steel "T" stakes and galvanized chain link fencing 1.2 m high. The fish lead was less than 1 m downstream from the transducer and extended 3 m offshore beyond the transducer. This distance provided sufficient offshore diversion for fish swimming upstream to be detected in the sonar beam. A short lead was appropriate for this bank because of the steep slope and short nearfield distance (0.83 m) of the DIDSON. The right bank was ensonified to a range of 40 m from the transducer, with two sampling zones, ranging from approximately 1 to 20 m and 20 to 40 m. Sonar control parameters included:

1) Nearshore zone - 0.83 m window start, 20.01 m window length, high frequency mode, and 7 frames per second, and

2) Offshore zone - 20.84 m window start, 20.01 m window length, low frequency mode, and 4 frames per second.

SONAR DATA PROCESSING AND PASSAGE ESTIMATION

Split-beam data was collected continuously in 60 min increments and saved to an external hard drive for tracking and counting. The operator opened each data file in an echogram viewer program and marked each upstream fish track by clicking a computer mouse (Figure 4). The number of marks for each hour was saved as a text file and recorded on a count form.

DIDSON data was collected in two 30 min samples each hour of the day. For the first 30 min of every hour, the DIDSON sampled the ensonified range from 1 m to 20 m (zone 1) and the second half of each hour sampled from 20 m to 40 m (zone 2). Upstream migrating fish were counted by marking each fish track on the echogram viewer program (Figure 4). Upstream direction of travel was verified using the DIDSON video feature. These counts were saved as text files and recorded on a count form.

The actual count for each 30 min sample was expanded for the full hour, where the number of minutes in a complete sample period m_s was divided by the number of minutes counted m_i, and then multiplied by the number of fish counted x in that period i. Passage y_i was estimated as:

$$\hat{y}_i = \left(m_s / m_i\right) x_i \quad , \tag{1}$$

and the estimated counts from zone 1 and zone 2 were summed for a total hourly count. The daily passage ŷ for zone z on day d was calculated by summing the hourly passage rates for each hour as follows:

$$\hat{y}_{dz} = \sum_{p=1}^{24} \frac{y_{dzp}}{h_{dzp}} \quad , \tag{2}$$

where h_{dzp} is the fraction of the hour sampled on day d, zone z, period p and y_{dzp} is the count for the same sample.

Treating the systematically sampled sonar counts as a simple random sample would yield an over-estimate of the variance of the total, since sonar counts are highly auto-correlated. To accommodate these data characteristics, a variance estimator based on the squared differences of successive observations was employed. The variance for the passage estimate for zone z on day d is estimated as:

$$\hat{V}_{y_{dz}} = 24^2 \frac{1 - f_{dz}}{n_{dz}} \frac{\sum_{p=2}^{n_{dz}} \left(\frac{y_{dzp}}{h_{dzp}} - \frac{y_{dz,p-1}}{h_{dz,p-1}} \right)^2}{2\left(n_{dz} - 1\right)} \quad . \tag{3}$$

Where n_{dz} is the number of samples in the day (24), f_{dz} is the fraction of the day sampled (12/24=0.5), and y_{dzp} is the hourly count for day d in zone z for sample p. Because passage estimates are assumed independent between zones and among days, the total variance was estimated as the sum of the variances:

$$\hat{V}ar(\hat{y}) = \sum_d \sum_z \hat{V}ar(\hat{y}_{dz}) \quad . \tag{4}$$

The reported variance reflects the sampling done on the right bank. The sampling variance for the left bank is inconsequential since the split-beam sonar sampled the entire range continuously.

Whenever a portion of a 60 minute period was missing on the left bank, passage was estimated using equation 1. If data from one or more complete sample periods was missing, passage for that portion of the day y_m was estimated by averaging passage from the sample periods immediately before y_b and after y_a the missing sample period(s), and then multiplying by the number of sample periods missed n:

$$\hat{y}_m = \left(\frac{y_b + y_a}{2} \right) n \quad . \tag{5}$$

If data from one or more complete days x_d were missing, passage for each missing day y_d was estimated using simple linear interpolation, based on the known passage y_b for the day immediately before the missing days and passage y_a for the day immediately after (x_a) the missing day(s).

$$\hat{y}_d = y_b + x_d \left(\frac{y_a - y_b}{x_a} \right) \quad . \tag{6}$$

As an example, if data from 9 days were missing, for the estimated passage on the third missing day (d=3), x_d=3, and x_a = 10.

The counts from each split-beam and DIDSON sample were entered into a Microsoft® Excel spreadsheet where counts were adjusted when data collection was interrupted. Brief interruptions intermittently occurred when routine maintenance (i.e. silt removal) or relocation of a transducer was required. Long-term interruptions also occurred when flooding or hazardous conditions forced removal of equipment. After editing was complete, an estimate of hourly, daily, and cumulative fish passage was produced and forwarded to the Fairbanks ADF&G office via satellite telephone each day. The estimates produced during the field season were further reviewed postseason and adjusted as necessary.

If a large number of chum salmon were passing on the last day of sonar operation, the estimate was expanded using a second order polynomial equation, where y_i is the ith daily passage estimate, L is the count on the last day of sonar operation, d is the total number of days expanding for, and x_i is the day number being estimated (where i = 1 through total number of days expanding for):

$$y_i = \frac{L}{d^2}(x_i - d)^2 \quad . \tag{7}$$

Postseason, the Chinook and chum salmon subsistence harvest from the Eagle area upstream of the sonar site was subtracted from the adjusted sonar estimate to give a border passage estimate for each species.

SPATIAL AND TEMPORAL DISTRIBUTIONS

Fish range distributions for Chinook and chum salmon were examined postseason by importing text files containing all fish track information into *R* statistical software package (R Development Core Team[2]) where the individual fish were binned by range. Microsoft® Excel was used to plot the binned data and investigate the spatial distribution of fish passing the sonar site. Histograms of passage by hour were created in Microsoft® Excel to investigate diel patterns of migration.

[2] R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, available for download: http://www.R-project.org.

Run timing of Chinook and chum salmon was examined inseason and postseason using information from the sonar estimate, fish range distribution, sample fishery catches, and local subsistence harvest.

SAMPLE FISHING

To monitor species composition and collect age, sex, length, and genetic samples, gillnets of mesh sizes 7.5 in and 5.25 in were drifted through three zones: left bank inshore (LBI), left bank nearshore (LBN), and left bank offshore (LBF) (Figure 2). Nets were 25 fathoms long, approximately 25 ft deep, and hung “even” at a 2:1 ratio of web to corkline. Gillnet webbing consisted of Momoi MTC or MT, shade 11, double knot multifilament nylon twine. In 2007, it was determined that the nets being used were too deep to effectively fish the inshore zone. Consequently, nets of shorter depth, (approximately 8 ft deep) were used for the inshore drifts only, with all other specifications remaining the same as the original nets.

Fishing for species composition and sample collection was conducted once daily from August 2 to October 2 between approximately 0800 and 1200 hours on the left bank. During the sampling period, both 5.25 in and 7.5 in nets were drifted twice within each of 3 zones (inshore, nearshore and offshore), for a total of 12 drifts. Drifts were targeted to be 6 minutes in duration, but were occasionally shortened as necessary to avoid snags or to limit catches and thus prevent mortalities during times of high fish passage. The inshore zone drifts were referred to as “beach walks” (Fleischman et al. 1995), where one person held onto the shore end of the net and led it downstream along the beach, while a boat drifted with the offshore end. The nearshore zone started approximately one net length from shore and the offshore zone started approximately two net lengths from shore (Figure 2). The order of drifts was 1) LBI, 2) LBN, and 3) LBF, with a minimum of 15 min between drifts in the same zone (Table 1). All drifts with one mesh size were completed before switching to another mesh size. Starting mesh sizes were alternated each day.

In an effort to collect more Chinook salmon age, sex, length, and genetic samples, additional fishing was conducted that targeted Chinook salmon. Between July 8 and August 1, fishing occurred twice per day from approximately 0800 to 1200 hours and again from approximately 1300 to 1700 hours to capture Chinook salmon. Between August 2 and August 15, Chinook salmon sample fishing was conducted once per day after species composition fishing was completed. Chinook salmon genetic and ASL samples were collected to estimate specific Canadian stock proportions and ASL composition of Chinook salmon entering Canada. Four different mesh sizes (5.25 in, 6.5 in, 7.5 in, and 8.5 in) were drifted in a rotating schedule over the course of the Chinook salmon run to effectively capture all size classes present (Table 1). Nets were 25 fathoms long, approximately 25 ft deep and hung “even” at a 2:1 ratio of web to corkline. Three net sizes were drifted for approximately 6 minutes each within the left bank nearshore (LBN), left bank offshore (LBF), and right bank nearshore (RBN). The right bank zone was located approximately 5 km downriver from the sonar site where river conditions were suitable for drift gillnetting on that bank (Figure 2). This resulted in 9 drifts during the Chinook salmon sample-fishing period.

Four times were recorded to the nearest second onto field data sheets for each drift: net start out *SO*, net full out *FO*, net start in *SI*, and net full in *FI*. For each drift, fishing time *t*, in minutes, was approximated as:

$$t = SI - FO + \frac{FO - SO}{2} + \frac{FI - SI}{2} \quad (8)$$

Total effort *e*, in fathom-hours, of drift *j* with mesh size *m* during fishing period *f* in zone *z* on day *d* was calculated as:

$$e_{dzfmj} = \frac{25 t_{dzfmj}}{60} \quad (9)$$

Captured salmon were sampled in the following ways:

For standard ASL samples, length (mideye to tail fork to nearest 5 mm), and sex (determined by external characteristics) were recorded. Three scales from Chinook salmon and one scale from chum salmon were removed from the preferred area of the fish - on the left side approximately two rows above the lateral line, in an area transected by a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Clutter and Whitesel 1956). All scale samples were cleaned and mounted on gum cards to be aged by ADF&G ASL lab in Anchorage. These scale data were used to estimate the age composition of salmon that pass the Eagle sonar site.

For genetic stock identification (GSI), an axillary process was clipped from each salmon. Chinook salmon samples were stored individually in a vial of ethanol, while chum salmon samples were stored in bulk collections of up to 200 samples. All samples were sent to ADF&G genetics laboratory and from there forwarded to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, BC for processing. Non-salmon species were measured from nose to tail fork, but were not sampled for other data. Captured fish were handled in a manner that minimized mortalities. Most captured fish were quickly sampled and returned to the river. Mortalities were distributed to local residents after sampling.

SPECIES DETERMINATION

Although the Chinook and fall chum salmon runs are considered discrete in time, some temporal overlap does occur. Inseason, tentative dates are chosen based on sonar counts, gillnet catches, and local harvest to represent the last day of the Chinook salmon run and the first day of the chum salmon run. After thorough examination of postseason sample fishery data, the tentative dates used may be changed to more accurately represent the runs. Sample fishery information was used to determine the specific date after which sonar counts were classified as chum salmon. This was ascertained using reverse-cumulative Chinook catches and cumulative chum catches. Estimates are reported as Chinook for days *d*, such that:

$$\sum_{d=n, i=Chinook}^{d} C_{id} > \sum_{d=1, i=chum}^{d} C_{id} \quad (10)$$

where *n* is most current day of fishing and *C* is the catch of species *i* on day *d.* The species crossover date is defined as the day where the inequality is no longer met.

Climate and Hydrologic Observations

Climate and hydrologic data were collected daily at approximately 1800 hours. Air and water temperatures, wind speed and direction, cloud cover and precipitation were recorded. Reported stream levels are taken from the U.S. Geological Survey's gauging station at Eagle, although water levels were carefully monitored at the sonar site as well.

RESULTS

Sonar Deployment

In 2011, both the right and left bank transducers were deployed in approximately the same locations that have been used in recent years. On July 4, the left bank sonar was deployed approximately 800 m downriver from the camp and the right bank sonar was deployed across the river approximately 700 m downriver from the camp (Figure 2). Zones of ensonification and bottom profile of the Yukon River at the sonar site can be found in Figure 3. The left bank profile was approximately linear, extending 300 m to the thalweg at a 2.3° slope. The right bank profile was less linear, shorter and steeper, extending 100 m to the thalweg at a 5.6° slope. The substrate at Six Mile Bend was large cobble to small boulder on the right bank, and small to medium sized cobble and silt on the left bank.

Chinook and Chum Salmon Passage Estimation

Inseason, August 15 was tentatively determined to be the last day of the Chinook salmon run based on relatively low sonar counts, gillnet catches and harvest information gathered from local subsistence fishermen. Fish range distribution from the sonar also was a primary indicator that the salmon run was changing from Chinook to chum salmon. The inseason species changeover date was adjusted postseason after thorough examination of sample fishery information. Analysis of reverse-cumulative Chinook catches and cumulative chum salmon catches showed that August 12 was the last date when the overall Chinook catch was more than the overall chum salmon catch. Reverse-cumulative Chinook catch and cumulative chum catch plotted by day from just prior to the date of the first chum salmon capture are depicted in Figure 5. The two lines cross at the point when the number of chum caught equals the number of Chinook salmon caught subsequent to that point.

The total passage estimate at the Eagle sonar site for Chinook salmon was 51,271 from July 5 to August 12, 2011 (Table 2). The first quarter point, midpoint, and third quarter point were on July 19, July 24, and July 29, respectively. Peak daily passage estimate of 3,460 Chinook salmon occurred on July 23 and 332 fish passed on August 12, the last day of estimating Chinook salmon passage (Figure 6). Sampling time missed during this period because of routine maintenance, system diagnostic tests, system malfunction, moving and aiming the transducer, or flooding, included 35.9 h on the left bank, 25.9 h on the right bank zone 1, and 36.6 h on the right bank zone 2 (Table 3). As noted in Table 3, sometimes the collection software from the split beam sonar over runs the sample time, resulting in a sample that is more than 1 h long. If at the end of a day the sample time is more than 24 h (1440 min) then the time in the table may show as negative. In this case, fish may be subtracted from the estimate, resulting in a negative number of fish. Postseason, the subsistence harvest from the Eagle area upstream of the sonar site was subtracted from the sonar estimate to produce a border passage estimate of 50,888 fish (Table 4). The preliminary subsistence harvest from the Eagle area upstream of the sonar was

383 fish (Deena Jallen, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication).

The total fall chum salmon passage estimate was 212,162 fish from August 13 to October 6, 2011 (Table 5). The first quarter point, midpoint, and third quarter point, while the sonar was operational, was on September 11, September 19, and September 26, respectively. Fall chum salmon passage peaked on September 25 with a daily estimate of 8,910 fish (Figure 6). Sampling time missed during this period because of routine maintenance, system diagnostic tests, system malfunction, moving and aiming the transducer, or flooding, included 12.3 h on the left bank, 6.2 h on the right bank zone 1, and 9.1 h on the right bank zone 2 (Table 6). Although chum salmon passage was decreasing on the last day of operation, 3,470 fish (approximately 1.6% of total) passed on October 6. Continuing chum salmon passage when the project was terminated prompted expansion of the sonar estimate, which was adjusted to 224,355 chum salmon (Table 4; Figure 6). The expansion was calculated using a second order polynomial equation extended to October 18 (Bonnie Borba, Commercial Fisheries Biologist, ADF&G; Fairbanks, personal communication). October 18 was chosen based on what is considered to be the most likely run timing scenario derived from 1982 to 2008 historical data collected at the DFO mark–recapture fish wheel project near the U.S./Canada border (Bonnie Borba, Commercial Fisheries Biologist, Fairbanks; personal communication). After the end of season expansion was included in the chum salmon estimate, the first quarter point, midpoint, and third quarter point, were September 11, September 20, and September 28, respectively. Postseason, the subsistence harvest from the Eagle area upstream of the sonar was subtracted from the sonar estimate to produce a border passage estimate of 211,930 fish (Table 4). The preliminary subsistence harvest from the Eagle area was 12,425 fish (Deena Jallen, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication).

Spatial and Temporal Distribution

Fish were shore oriented on both banks (Figures 7 and 8). On the left bank during the Chinook salmon run, 99% of the fish were detected within 70 m of the transducer. On the right bank, 99% of the fish were detected within 34 m of the transducer. During the fall chum salmon run on the left bank, 99% of the fish were detected within 35 m of the transducer. On the right bank, 99% of the fish were detected within 10 m of the transducer. The percentage of fish passage estimated by bank for the Chinook salmon season was approximately 80% on the left bank and 20% on the right bank. During the fall chum salmon run, approximately 59% migrated on the left bank and 41% on the right bank.

On average, Chinook salmon passage along the left and right bank did not fluctuate much between daylight hours and periods of darkness (Figure 9). On average more chum salmon passed along the right bank during daylight hours compared to periods of darkness while fewer chum salmon passed along the left bank during daylight hours compared to periods of darkness (Figure 10). Overall, when both banks are combined, there was very little diel fluctuation at the project site for both species.

Sample Fishing

A total of 511 Chinook and 890 chum salmon were captured in drift gillnets between July 8 and October 2 (Table 7). Fishing for species composition and sample collection occurred from August 2 to October 2, and additional Chinook salmon sample fishing occurred from July 8 to

August 15. Drifts during species composition fishing caught 26 Chinook and 889 chum salmon. Drifts during Chinook salmon sample fishing caught 485 Chinook and 1 chum salmon. Additionally, 10 sheefish *Stenodus leucichthys*, 7 whitefish *Coregonus* spp. and 1 burbot *Lota lota* were captured during species composition fishing. The number of Chinook and chum salmon captured in drift gillnets by sampling purpose (species composition sampling or Chinook salmon sampling), zone and mesh size are contained in Tables 8 and 9. There were 2 Chinook and 1 chum salmon capture mortalities. An additional 3 Chinook salmon were observed to have clipped adipose fins indicating they held coded wire tags from the hatchery in Whitehorse, YT. These fish were retained and the heads sent to the ADF&G Mark, Tag and Age Lab in Juneau, AK. The fish were then distributed to local area residents and added to the total subsistence harvest. No fishing occurred on July 29 because the fishing crew was needed for gear repair.

Chinook salmon samples collected from driftnets were composed of 263 (51.5%) males and 248 (48.5%) females. Chum salmon samples from driftnets were composed of 556 (62.5%) males and 334 (37.5%) females. ASL samples from 510 Chinook and 886 chum salmon were collected and sent to the ADF&G age determination laboratory in Anchorage for processing. Genetic samples from 500 Chinook and 890 chum salmon were collected and sent to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, BC for processing.

Climate and Hydrologic Observations

Details of weather and water observations recorded at the sonar site are shown in Appendix A1. Water temperature decreased over the course of the season with a maximum daily recording of 17°C and a minimum of 3°C. The water level was high upon arrival at the project site on July 1, and remained higher than the 1993 through 2010 historic mean the entire season (Figure 11). Water level decreased over the duration of the season, with several temporary and dramatic increases following substantial rain events. Overall, between July 1 and October 6 the water level decreased 10.6 ft from 22.5 ft to 11.9 ft. The lowest water level recorded during the season was 11.9 ft on October 6, while the highest was 22.5 ft on July 1.

DISCUSSION

Sonar Deployment and Operation

The split-beam and DIDSON systems performed well over the entire season with no major technical difficulties or failures. Only when water levels were extremely high and the Yukon River demonstrated an abnormally heavy silt load were sonar operations interrupted. Heavy rains and flood events characterized July and August. Rapid water level fluctuations coupled with substantial debris necessitated moving the transducers and fish leads to deeper or shallower water. The left bank fish lead collapsed during high water events, and multiple panels had to be recovered and removed from the water on occasions when the high water flow and debris load compromised their stability. When the silt load was exceptionally high, sonar detection ranges were diminished. Detection ranges for both sonars were reduced to approximately half of the normal counting range on July 17 and 18, during the Chinook salmon run. On July 17 as the silt load increased, signal strength at range began to diminish. As there were few fish at far ranges to begin with, and the hourly estimates did not show a discernible change, no adjustment was made to the daily estimate, although some fish may have been missed. By early morning on July 18, it became obvious, based on diminished signal strength at even closer range, and abnormally low counts compared to previous hours, that fish were being missed by the sonar. This continued until late that evening, and by July 19, detection appeared to be back to normal. The estimate for entire day of July 18 was interpolated. In contrast, weather and river conditions during the chum salmon run in late August and September was very favorable for sonar operation. The DIDSON, with its wide beam angle (14°), is well suited for the right bank, where the profile is steep and less linear than the left bank. The split-beam system worked without malfunction, and appeared to have satisfactory detection nearshore, while still detecting targets adequately at 150 m.

Processing procedures for both DIDSON and split-beam files worked well for estimating salmon passage at the site. All data files were easily processed in a reasonable amount of time. The improved background removal and color by angle features to the echogram viewing program used for counting fish from the split-beam data files made distinguishing fish tracks, particularly for chum passing near the transducer, easier. The updated version allowed users to adjust the level of background removed, depending on counting conditions.

Chinook and Chum Salmon Passage Estimation

The main purpose of this study was to estimate the passage and timing of Chinook and fall chum salmon to Canada in the mainstem of the Yukon River using hydroacoustics. The Chinook salmon border passage estimate of 50,888 is 7.9% below the 2005 to 2010 average sonar border passage estimate of 55,228. Timing of the 2011 Chinook salmon run was 1 day early based on 2006–2010 mean quartile passage dates. The fall chum salmon border passage estimate of 213,708 is 21.3% above the 2006 to 2010 average sonar border passage estimate of 176,110 fish. Timing of the 2011 chum salmon run was 2 days early based on 2006–2010 mean quartile passage dates that include end of season expansions.

Spatial and Temporal Distributions

Based on sample fishing results and range distributions observed with the sonar, very few fish migrate upstream in the unensonified portion of the river. The majority of fish migrate within 40 m of shore on both banks. The right bank DIDSON was aimed to ensonify to a range of 40 m, and the left bank split-beam system was aimed to ensonify to a range of 150 m. Because chum salmon tend to swim closer to shore, the range for the left bank split-beam system was reduced to 75 m on August 17 to allow faster ping rates and improved detection near shore. The diel migration pattern of chum salmon observed was similar to past years. Average upstream migration was greatest in periods of darkness or suppressed light on the left bank and greatest during daylight hours on the right bank. The diel migration pattern of Chinook salmon was similar to past years, in that, there is not much if any difference in passage between day and night.

Sample Fishing and Species Determination

Fishing was conducted with drift gillnets to capture a representative sample of fish migrating past the sonar site. If fishing effort for both species is approximately the same, this method should recognize a particular date when chum salmon compose more of the sonar count than Chinook salmon, with a minimum error due to species misclassification. However, misclassification rates are relatively insensitive to changeover date selection of species because of the typically low passage rates observed around this time (Withler 2006).

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TABLES AND FIGURES

Table 1.–Net schedules for species composition and additional Chinook salmon samples, all zones, 2011.

Sampling Purpose	Day	Drift		
		1	2	3
Species Composition	1	5.25"	7.50"	
	2	7.50"	5.25"	
Additional Chinook salmon samples	1	5.25"	6.50"	7.50"
	2	7.50"	8.50"	6.50"
	3	6.50"	5.25"	8.50"
	4	8.50"	7.50"	5.25"

Table 2.–Estimated daily and cumulative Chinook salmon passage by bank, Eagle sonar, 2011.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	Proportion of Total Passage
7/05 [a]	70	30	100	70	30	100	0.00
7/06	136	83	219	206	113	319	0.01
7/07	194	147	341	400	260	660	0.01
7/08	316	120	436	716	380	1,096	0.02
7/09	313	91	404	1,029	471	1,500	0.03
7/10	352	70	422	1,381	541	1,922	0.04
7/11	365	138	503	1,746	679	2,425	0.05
7/12	296	130	426	2,042	809	2,851	0.06
7/13	325	332	657	2,367	1,141	3,508	0.07
7/14	726	415	1,141	3,093	1,556	4,649	0.09
7/15	1,200	480	1,680	4,293	2,036	6,329	0.12
7/16	1,535	449	1,984	5,828	2,485	8,313	0.16
7/17 [b]	1,622	222	1,844	7,450	2,707	10,157	0.20
7/18 [b,c]	1,699	208	1,907	9,149	2,915	12,064	0.24
7/19	1,776	194	1,970	10,925	3,109	14,034	0.27 [d]
7/20	699	234	933	11,624	3,343	14,967	0.29
7/21	937	797	1,734	12,561	4,140	16,701	0.33
7/22	2,009	1,100	3,109	14,570	5,240	19,810	0.39
7/23	2,825	635	3,460	17,395	5,875	23,270	0.45
7/24	2,912	478	3,390	20,307	6,353	26,660	0.52 [e]
7/25	2,733	427	3,160	23,040	6,780	29,820	0.58
7/26	2,671	308	2,979	25,711	7,088	32,799	0.64
7/27	1,949	168	2,117	27,660	7,256	34,916	0.68
7/28	1,850	184	2,034	29,510	7,440	36,950	0.72
7/29	1,419	314	1,733	30,929	7,754	38,683	0.75
7/30	1,286	372	1,658	32,215	8,126	40,341	0.79
7/31	1,179	326	1,505	33,394	8,452	41,846	0.82
8/01	1,244	306	1,550	34,638	8,758	43,396	0.85
8/02	1,109	224	1,333	35,747	8,982	44,729	0.87
8/03	869	148	1,017	36,616	9,130	45,746	0.89
8/04	811	127	938	37,427	9,257	46,684	0.91
8/05	742	159	901	38,169	9,416	47,585	0.93
8/06	593	191	784	38,762	9,607	48,369	0.94
8/07	633	142	775	39,395	9,749	49,144	0.96
8/08	515	101	616	39,910	9,850	49,760	0.97
8/09	379	100	479	40,289	9,950	50,239	0.98
8/10	306	74	380	40,595	10,024	50,619	0.99
8/11	248	72	320	40,843	10,096	50,939	0.99
8/12 [f]	206	126	332	41,049	10,222	51,271	1.00
SE [g]		135				135	

[a] Right and left bank sonar operational.

[b] High silt load and debris affected counts.

[c] High silt load and debris affected counts, counts interpolated.

[d] Boxed area identifies second and third quartile of run.

[e] Bold box identifies median day of passage.

[f] Last day of Chinook salmon counts.

[g] Sampling error associated with the left bank was treated as insignificant since data was collected 24 hours per day over the sampling range.

Table 3.–Number of minutes by bank and day that were adjusted, to calculate the hourly or daily Chinook salmon passage, and the resulting number of fish either added or subtracted from estimate.

	Left Bank (0-150m)		Right Bank (0-20m)		Right Bank (20-40m)	
Date	Minutes	Fish	Minutes	Fish	Minutes	Fish
7/5	6.1	0	480.0	20	480.0	0
7/6	11.4	1	60.0	6	90.0	3
7/7	8.3	0	13.0	2	30.0	1
7/8	8.4	0	0.0	0	30.0	0
7/9	12.1	2	6.0	1	30.0	0
7/10	38.6	11	38.7	2	6.6	0
7/11	11.0	1	0.0	0	0.0	0
7/12	110.4	29	135.4	7	47.5	-1
7/13	7.3	0	0.0	0	0.0	0
7/14	1.8	-2	0.0	0	30.0	7
7/15	7.6	1	0.0	0	0.0	0
7/16	-5.7	-11	0.0	0	60.0	21
7/17	0.6	-7	0.0	0	0.0	0
7/18	1,440.0	1,699	720.0	185	720.0	23
7/19	7.8	10	17.8	4	30.0	0
7/20	8.7	0	0.0	0	0.0	0
7/21	9.0	0	30.0	33	0.0	0
7/22	9.0	14	0.0	0	0.0	0
7/23	9.5	23	30.0	21	0.0	0
7/24	8.9	22	0.0	0	0.0	0
7/25	7.6	17	-90.0	-39	120.0	4
7/26	7.8	17	-120.0	-74	240.0	8
7/27	8.1	12	0.0	0	0.0	0
7/28	8.2	9	0.0	0	30.0	2
7/29	9.0	3	0.0	0	0.0	0
7/30	9.3	0	0.0	0	0.0	0
7/31	8.8	0	0.0	0	0.0	0
8/1	9.1	0	30.0	12	0.0	0
8/2	8.4	0	8.7	0	0.0	0
8/3	121.1	63	34.1	6	73.1	0
8/4	8.4	0	0.0	0	30.0	3
8/5	8.8	0	6.4	1	0.0	0
8/6	177.9	73	124.3	37	120.0	16
8/7	9.0	0	0.0	0	0.0	0
8/8	8.6	0	30.0	5	30.0	0
8/9	8.8	0	0.0	0	0.0	0
8/10	8.0	0	0.0	0	0.0	0
8/11	8.3	0	0.0	0	0.0	0
8/12	9.1	0	0.0	0	0.0	0
Total	2,155.1 (35.9 h)	1,987	1,554.4 (25.9 h)	229	2,197.2 (36.6 h)	87

Note: Negative numbers are result of collection software over running the sample period. See *Results* section for details.

Table 4.–Eagle sonar estimate, Eagle area subsistence harvest, and border passage estimates, 2005–2011.

	Sonar Estimate		Eagle Area Subsistence Harvest[a]		U.S. Sonar Mainstem Border Passage Estimate	
Date	Chinook	chum	Chinook	chum	Chinook	chum
2005	81,528	ND	2,566	ND	78,962	ND
2006	73,691	236,386	2,303	17,775	71,388	218,611
2007	41,697	282,670 [b]	1,999	18,691	39,698	263,979
2008	38,097	193,397 [b]	815	11,755	37,282	181,642
2009	69,957	101,734 [b]	382	6,995	69,575	94,739
2010	35,074	132,930 [b]	609	11,350	34,465	121,580
2011	51,271	224,355 [b]	383	12,425	50,888	211,930

Note: Estimates for subsistence caught salmon between the sonar site and border (Eagle area) prior to 2008 include an unknown portion caught below the sonar site. This number is most likely in the hundreds for Chinook salmon, and a few thousand for chum salmon. Starting in 2008, the estimates for subsistence caught salmon only include salmon harvested between the sonar site and the U.S./Canada border.

[a] Except for 2005, 2008 and 2009, subsistence estimates are preliminary.

[b] Expanded sonar estimate, includes expansion for fish that may have passed after sonar operations ceased.

Table 5.–Estimated daily and cumulative chum salmon passage by bank, Eagle sonar, 2011.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	Proportion of Total Passage
8/13 [a]	160	72	232	160	72	232	0.00
8/14	124	106	230	284	178	462	0.00
8/15	121	86	207	405	264	669	0.00
8/16	52	84	136	457	348	805	0.00
8/17	61	64	125	518	412	930	0.00
8/18	131	34	165	649	446	1,095	0.01
8/19	131	34	165	780	480	1,260	0.01
8/20	140	32	172	920	512	1,432	0.01
8/21	131	42	173	1,051	554	1,605	0.01
8/22	119	38	157	1,170	592	1,762	0.01
8/23	134	42	176	1,304	634	1,938	0.01
8/24	169	25	194	1,473	659	2,132	0.01
8/25	229	32	261	1,702	691	2,393	0.01
8/26	293	42	335	1,995	733	2,728	0.01
8/27	350	22	372	2,345	755	3,100	0.01
8/28	328	74	402	2,673	829	3,502	0.02
8/29	303	86	389	2,976	915	3,891	0.02
8/30	285	116	401	3,261	1,031	4,292	0.02
8/31	235	117	352	3,496	1,148	4,644	0.02
9/01	388	172	560	3,884	1,320	5,204	0.02
9/02	571	228	799	4,455	1,548	6,003	0.03
9/03	1,036	610	1,646	5,491	2,158	7,649	0.04
9/04	1,890	1,256	3,146	7,381	3,414	10,795	0.05
9/05	2,666	1,748	4,414	10,047	5,162	15,209	0.07
9/06	3,554	2,222	5,776	13,601	7,384	20,985	0.10
9/07	3,838	2,682	6,520	17,439	10,066	27,505	0.13
9/08	3,988	2,944	6,932	21,427	13,010	34,437	0.16
9/09	3,798	3,298	7,096	25,225	16,308	41,533	0.20
9/10	3,540	3,434	6,974	28,765	19,742	48,507	0.23
9/11	4,339	3,254	7,593	33,104	22,996	56,100	0.26 [b]
9/12	4,367	2,500	6,867	37,471	25,496	62,967	0.30
9/13	4,433	2,298	6,731	41,904	27,794	69,698	0.33
9/14	3,788	3,224	7,012	45,692	31,018	76,710	0.36
9/15	3,733	2,344	6,077	49,425	33,362	82,787	0.39
9/16	3,598	2,322	5,920	53,023	35,684	88,707	0.42
9/17	3,860	2,288	6,148	56,883	37,972	94,855	0.45
9/18	3,605	2,032	5,637	60,488	40,004	100,492	0.47
9/19	3,740	1,816	5,556	64,228	41,820	106,048	0.50 [c]
9/20	4,121	1,560	5,681	68,349	43,380	111,729	0.53
9/21	4,241	2,207	6,448	72,590	45,587	118,177	0.56
9/22	4,016	2,670	6,686	76,606	48,257	124,863	0.59
9/23	4,250	3,163	7,413	80,856	51,420	132,276	0.62
9/24	4,836	3,716	8,552	85,692	55,136	140,828	0.66
9/25	4,826	4,084	8,910	90,518	59,220	149,738	0.71
9/26	5,006	3,818	8,824	95,524	63,038	158,562	0.75
9/27	4,558	3,976	8,534	100,082	67,014	167,096	0.79
9/28	3,887	3,656	7,543	103,969	70,670	174,639	0.82

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Table 5.–Page 2 of 2.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	Proportion of Total Passage
9/29	3,587	2,784	6,371	107,556	73,454	181,010	0.85
9/30	3,258	2,454	5,712	110,814	75,908	186,722	0.88
10/01	2,992	2,288	5,280	113,806	78,196	192,002	0.90
10/02	2,453	1,950	4,403	116,259	80,146	196,405	0.93
10/03	2,443	1,897	4,340	118,702	82,043	200,745	0.95
10/04	2,124	1,858	3,982	120,826	83,901	204,727	0.96
10/05	2,153	1,812	3,965	122,979	85,713	208,692	0.98
10/06 [d]	1,744	1,726	3,470	124,723	87,439	212,162	1.00
SE [e]		654				654	

[a] First day of chum salmon counts.

[b] Boxed area identifies second and third quartile of run.

[c] Bold box identifies median day of passage.

[d] Last day of sonar operation.

[e] Sampling error associated with the left bank was treated as insignificant since data was collected 24 hours per day over the sampling range.

Table 6.–Number of minutes by bank and day that were adjusted, to calculate the hourly or daily chum salmon passage, and the resulting number of fish either added or subtracted from estimate.

	Left Bank (0-75m)		Right Bank (0-20m)		Right Bank (20-40m)	
Date	Minutes	Fish	Minutes	Fish	Minutes	Fish
8/13	7.9	0	0.0	0	30.0	0
8/14	7.8	0	0.0	0	0.0	0
8/15	8.4	0	0.0	0	0.0	0
8/16	7.2	0	0.0	0	0.0	0
8/17	1.1	0	0.0	0	0.0	0
8/18	9.2	0	0.0	0	0.0	0
8/19	11.7	0	0.0	0	0.0	0
8/20	23.3	2	0.0	0	0.0	0
8/21	1.4	0	0.0	0	30.0	0
8/22	1.9	0	0.0	0	0.0	0
8/23	1.4	0	0.0	0	0.0	0
8/24	0.7	0	6.8	1	16.4	0
8/25	1.2	0	0.0	0	30.0	0
8/26	0.5	0	0.0	0	0.0	0
8/27	1.3	0	0.0	0	0.0	0
8/28	1.8	0	17.4	0	2.5	0
8/29	1.4	0	0.0	0	0.0	0
8/30	1.3	0	0.0	0	0.0	0
8/31	10.8	0	8.0	3	0.0	0
9/1	0.4	0	0.0	0	0.0	0
9/2	2.0	0	14.0	4	24.0	0
9/3	0.3	0	0.0	0	0.0	0
9/4	0.9	0	0.0	0	0.0	0
9/5	1.3	0	0.0	0	14.0	0
9/6	1.7	0	0.0	0	0.0	0
9/7	1.2	0	0.0	0	0.0	0
9/8	1.8	0	0.0	0	30.0	0
9/9	1.4	-1	0.0	0	0.0	0
9/10	1.6	0	0.0	0	0.0	0
9/11	269.2	780	0.0	0	0.0	0
9/12	1.4	0	0.0	0	30.0	0
9/13	1.2	-1	0.0	0	0.0	0
9/14	0.8	0	0.0	0	0.0	0
9/15	1.9	0	0.0	0	0.0	0
9/16	6.7	8	0.0	0	22.0	0
9/17	1.4	0	0.0	0	0.0	0
9/18	1.6	0	0.0	0	0.0	0
9/19	1.1	0	0.0	0	0.0	0
9/20	0.0	-1	0.0	0	0.0	0
9/21	0.5	-1	14.0	53	30.0	0
9/22	0.9	-1	0.0	0	0.0	0
9/23	124.9	418	64.1	187	66.3	0
9/24	0.1	-2	0.0	0	0.0	0
9/25	2.8	2	0.0	0	0.0	0
9/26	2.3	3	0.0	0	30.0	0
9/27	2.4	1	120.0	518	90.0	0
9/28	199.5	626	120.0	440	90.0	0

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Table 6.–Page 2 of 2.

Date	Left Bank (0-75m) Minutes	Fish	Right Bank (0-20m) Minutes	Fish	Right Bank (20-40m) Minutes	Fish
9/29	0.8	3	0.0	0	0.0	0
9/30	1.4	0	0.0	0	0.0	0
10/1	2.3	1	0.0	0	0.0	0
10/2	0.8	-1	0.0	0	0.0	0
10/3	1.3	0	10.3	45	9.4	0
10/4	1.2	0	0.0	0	0.0	0
10/5	0.6	0	0.0	0	0.0	0
10/6	0.7	0	0.0	0	0.0	0
Total	740.7 (12.3 h)	1,836	374.6 (6.2 h)	1,251	544.6 (9.1 h)	0

Note: Negative numbers are result of collection software over running sample period. See *Results* section for details.

Table 7.–Fish caught with gillnets at the Eagle sonar project site, 2011.

Species	Species Composition Fishing	Chinook Salmon Sample Fishing	Total
Chinook	26	485	511
chum	889	1	890
sheefish	10	0	10
whitefish	7	0	7
burbot	1	0	1
Total	933	486	1,419

Table 8.–Species composition fishing effort, catch, and percentage for Chinook and chum salmon, by zone and mesh size, Eagle sonar project site, 2011.

Zone	Mesh Size (inches)	Effort (fathom hours)	Chinook Catch	Chinook Percent	Chum Catch	Chum Percent
LBI	5.25	375.68	11	42.3	653	73.5
	7.50	347.56	8	30.8	146	16.4
Total		723.24	19	73.1	799	89.9
LBN	5.25	346.97	1	3.8	68	7.7
	7.50	340.49	6	23.1	18	2.0
Total		687.46	7	26.9	86	9.7
LBF	5.25	337.31	0	0.0	2	0.2
	7.50	333.07	0	0.0	2	0.2
Total		670.38	0	0.0	4	0.4
Grand Total		2081.08	26	100.0	889	100.0

Note: Left bank inshore (LBI), Left bank nearshore (LBN), and Left bank offshore (LBF).

Table 9.–Chinook salmon sample fishing effort, catch, and percentage for Chinook and chum salmon, by zone and mesh size, Eagle sonar project site, 2011.

Zone	Mesh Size (inches)	Effort (fathom hours)	Chinook Catch	Chinook Percent	Chum Catch	Chum Percent
	5.25	129.03	33	6.8	0	0.0
LBN	6.50	135.15	48	10.0	0	0.0
	7.50	136.39	32	6.6	0	0.0
	8.50	143.65	53	11.0	0	0.0
Total		544.22	166	34.4	0	0.0
	5.25	136.82	68	14.1	0	0.0
RBN	6.50	137.76	81	16.8	1	100.0
	7.50	141.30	75	15.6	0	0.0
	8.50	133.24	65	13.5	0	0.0
Total		549.12	289	60.0	1	100.0
	5.25	127.46	7	1.5	0	0.0
LBF	6.50	133.16	15	3.1	0	0.0
	7.50	125.74	3	0.6	0	0.0
	8.50	126.54	2	0.4	0	0.0
Total		512.90	27	5.6	0	0.0
Grand Total		1,606.24	482	100.0	1	100.0

Note: Left bank nearshore (LBN), Right bank nearshore (RBN), and Left bank offshore (LBF).

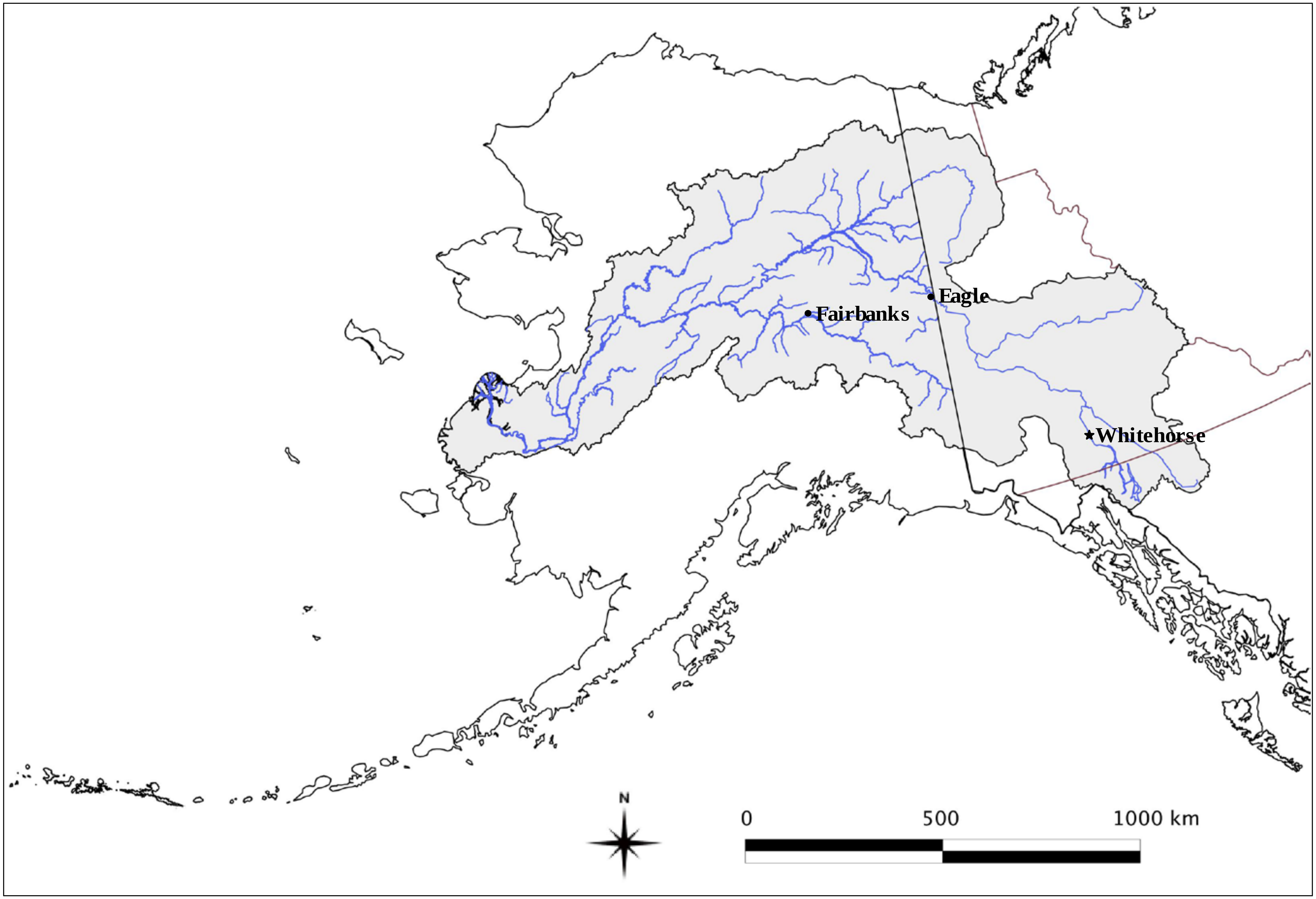


Figure 1.–Yukon River drainage.

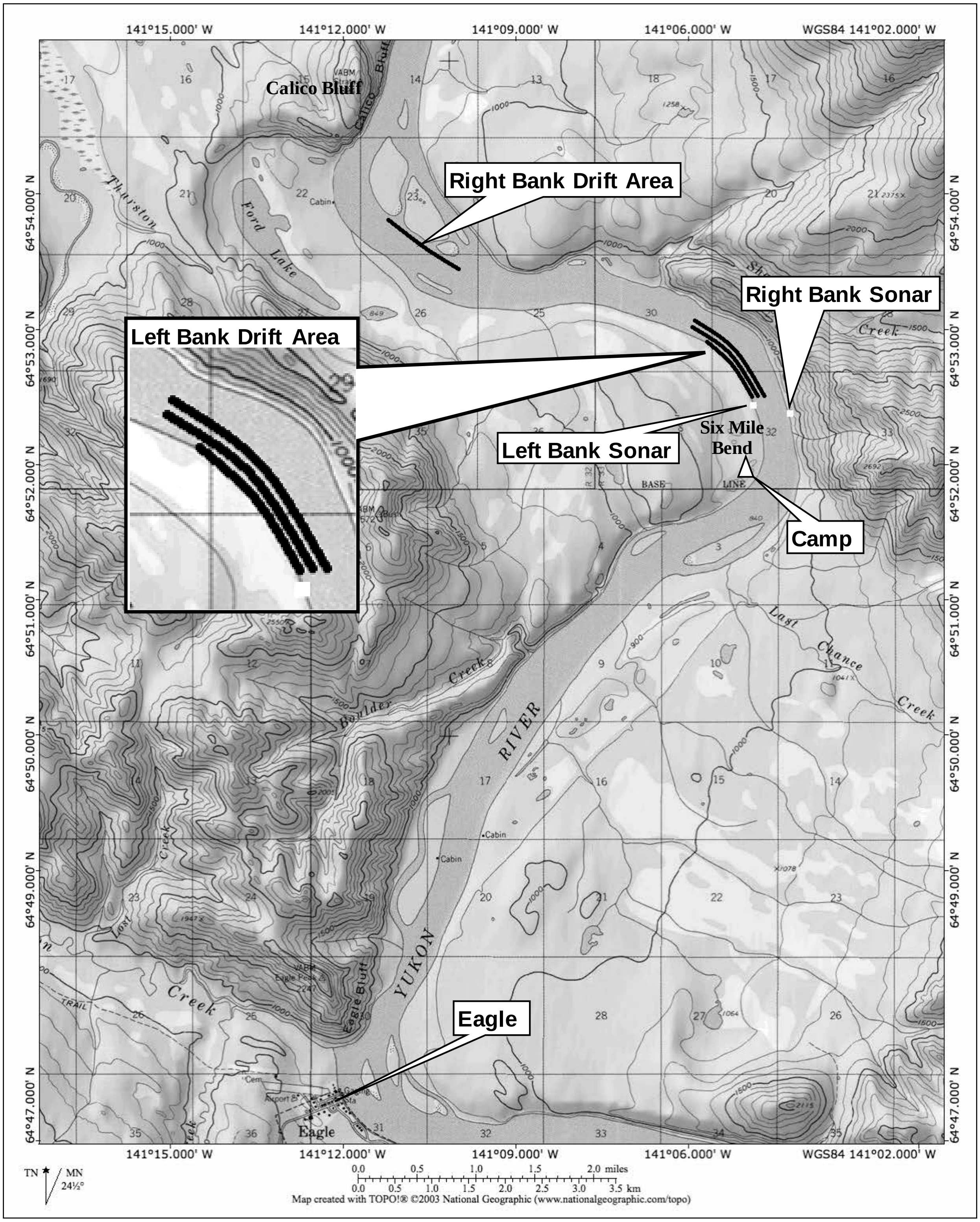


Figure 2.–Eagle sonar project site at Six Mile Bend, showing sonar and drift gillnet fishing locations.

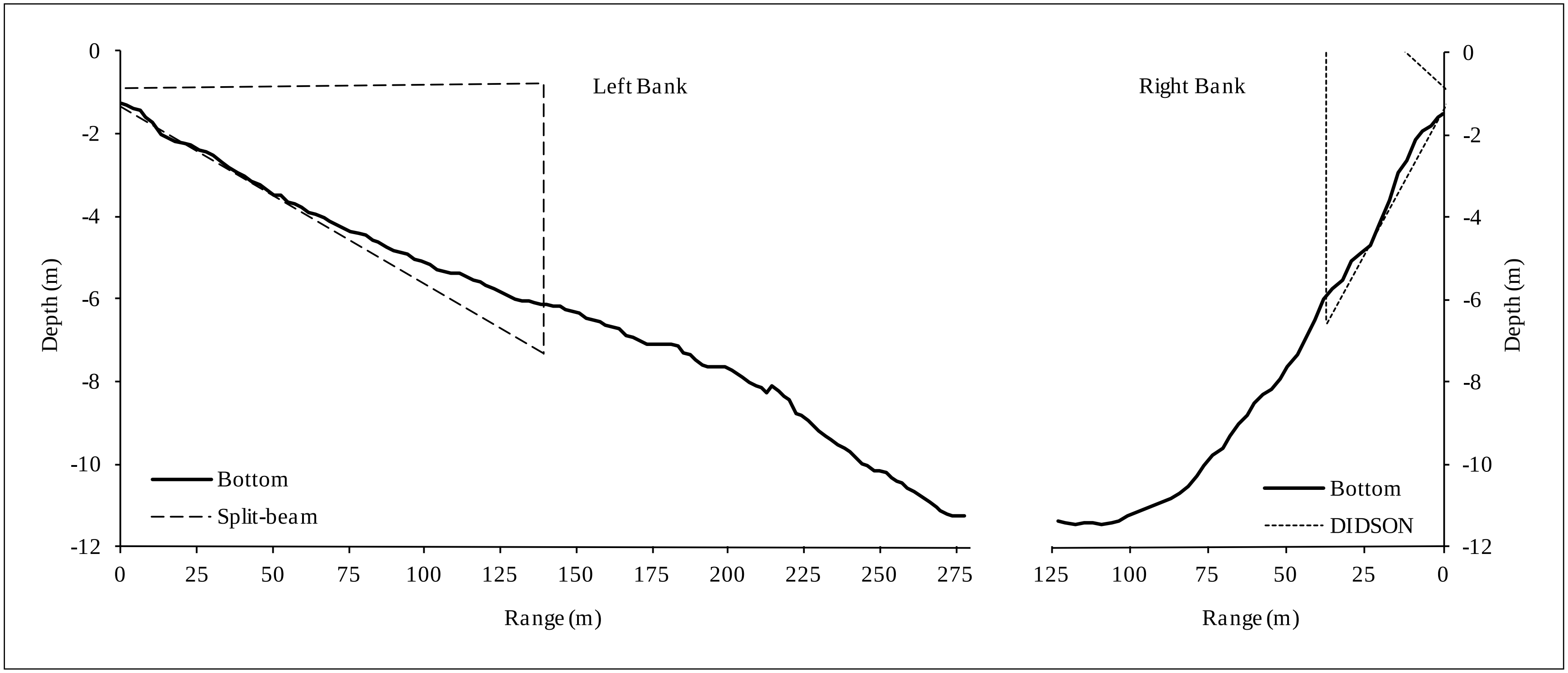
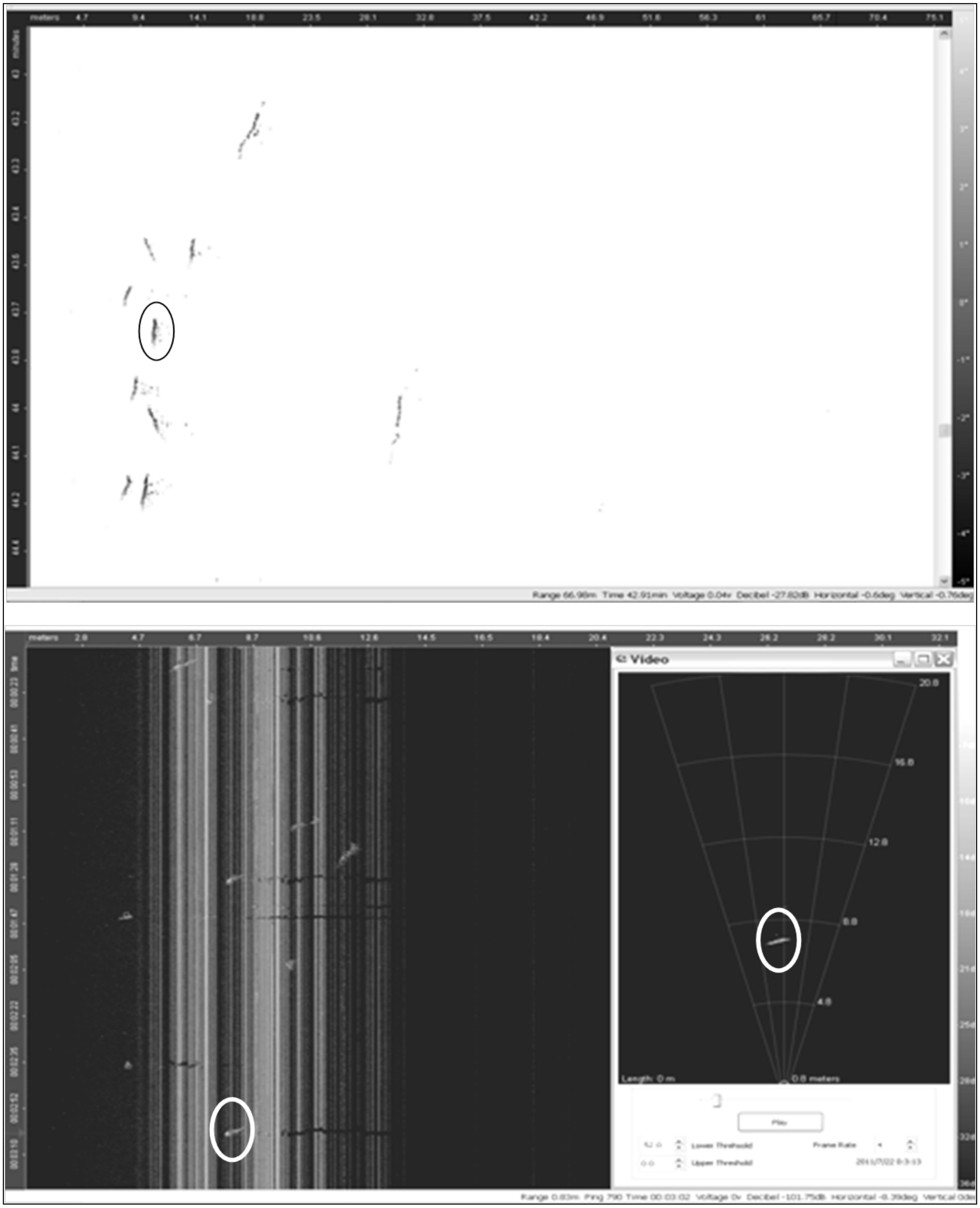


Figure 3.–Depth profile (downstream view), and ensonified zones of Yukon River at Eagle sonar project site, 2011.



Note: Ellipse encompasses typical upstream migrating salmon.

Figure 4.–Screenshots of echograms used to count fish from split-beam sonar data files (top), and DIDSON data files (bottom).

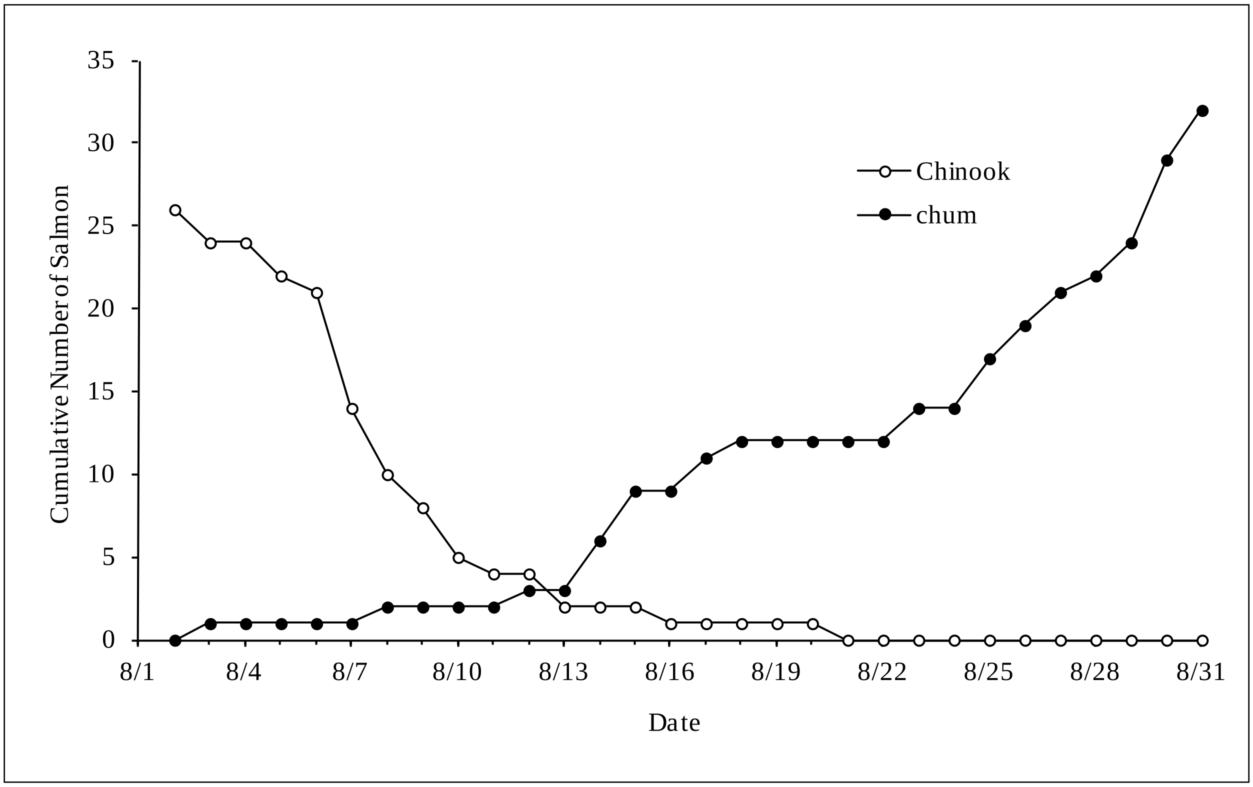


Figure 5.–Species changeover dates (August 12–13) determined from reverse cumulative Chinook and cumulative chum salmon catches at the Eagle sonar project site, 2011.

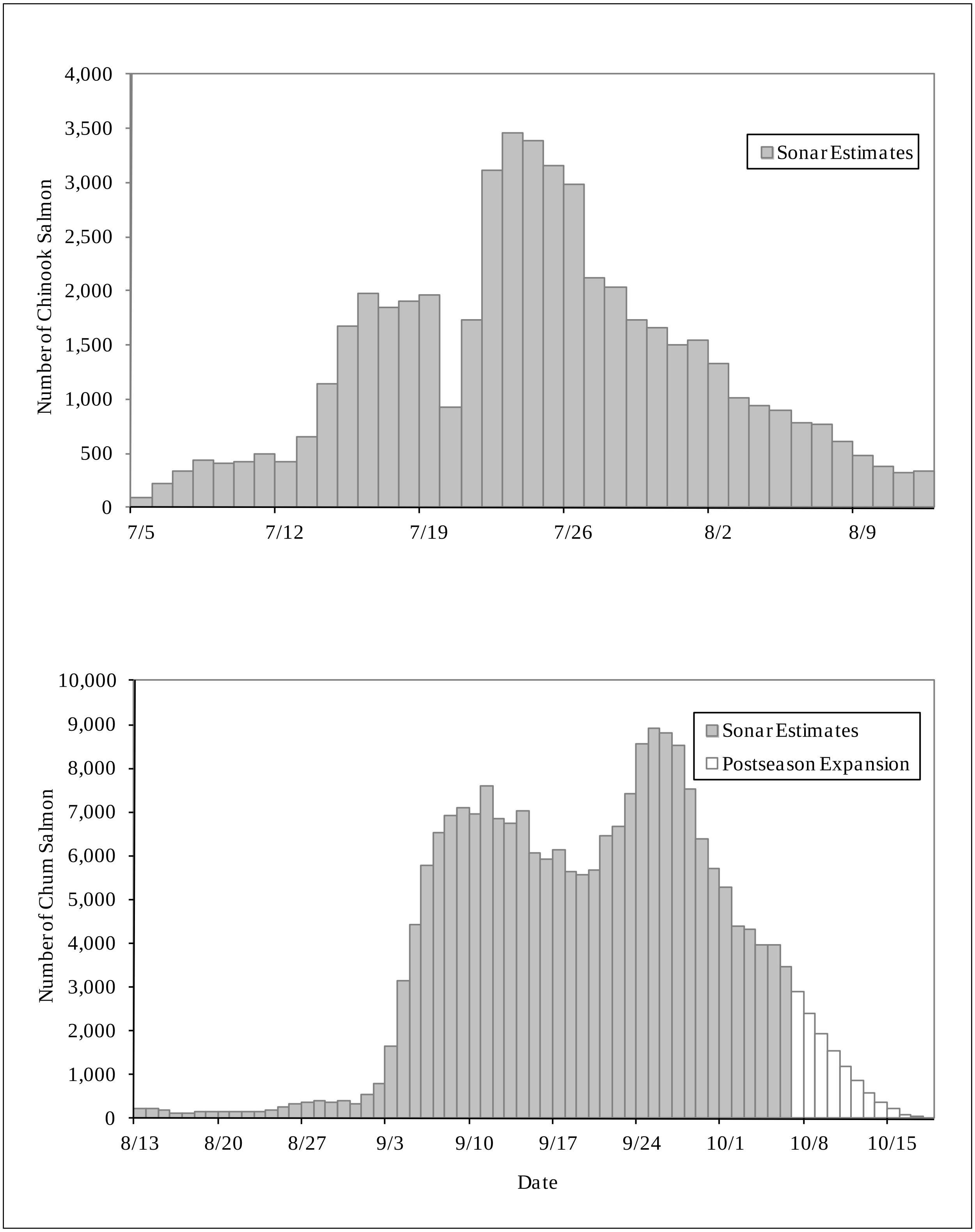


Figure 6.–Daily sonar estimates for Chinook salmon, July 5 through August 12, 2011 (top), and daily sonar estimates with postseason chum salmon expansion estimates for chum salmon, August 13 through October 18 (bottom).

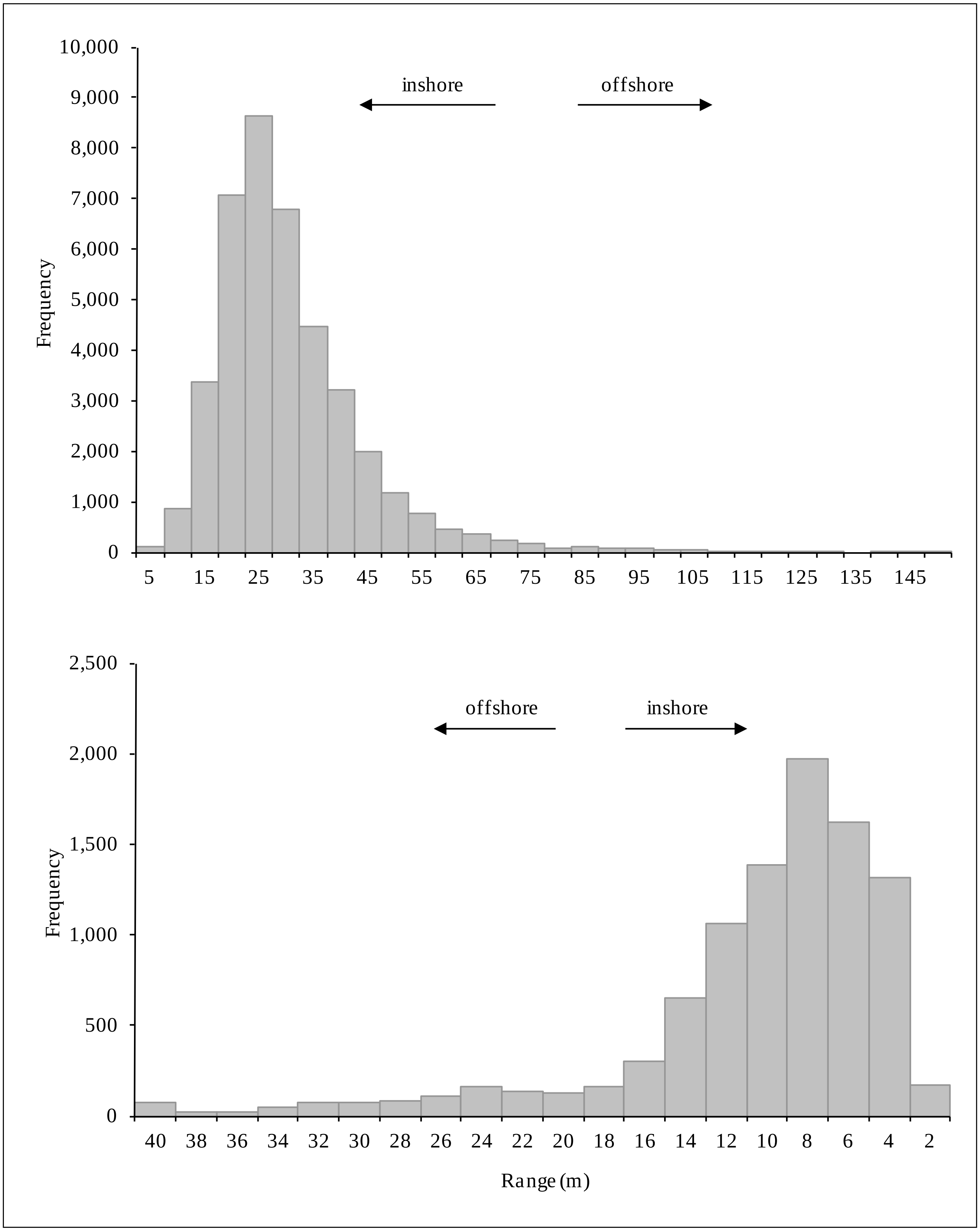


Figure 7.–Left bank (top) and right bank (bottom) horizontal distribution of upstream Chinook salmon passage in the Yukon River at Eagle sonar project site, July 5 through August 12, 2011.

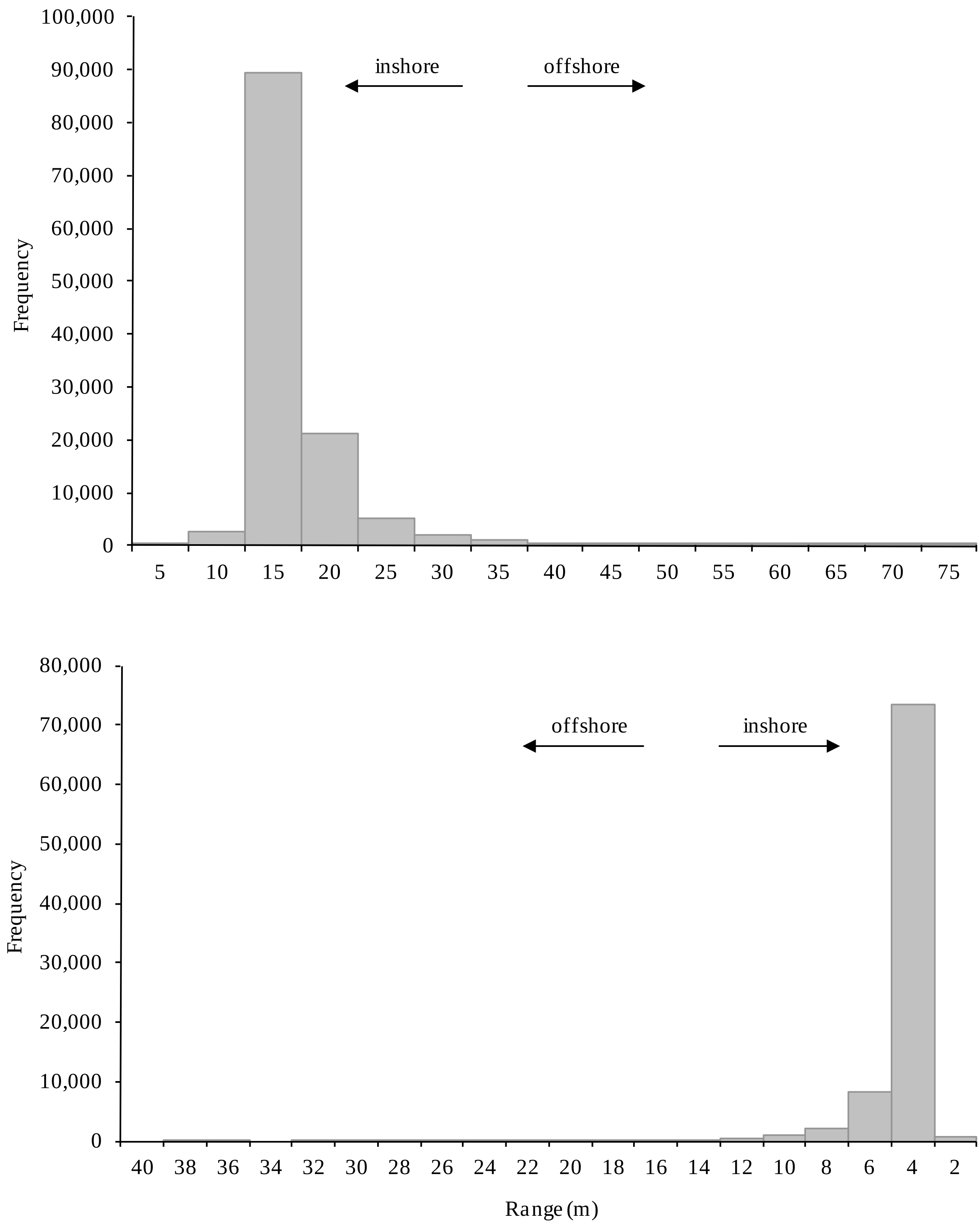


Figure 8.–Left bank (top) and right bank (bottom) horizontal distribution of upstream chum salmon passage in the Yukon River at Eagle sonar project site, August 13 through October 6, 2011.

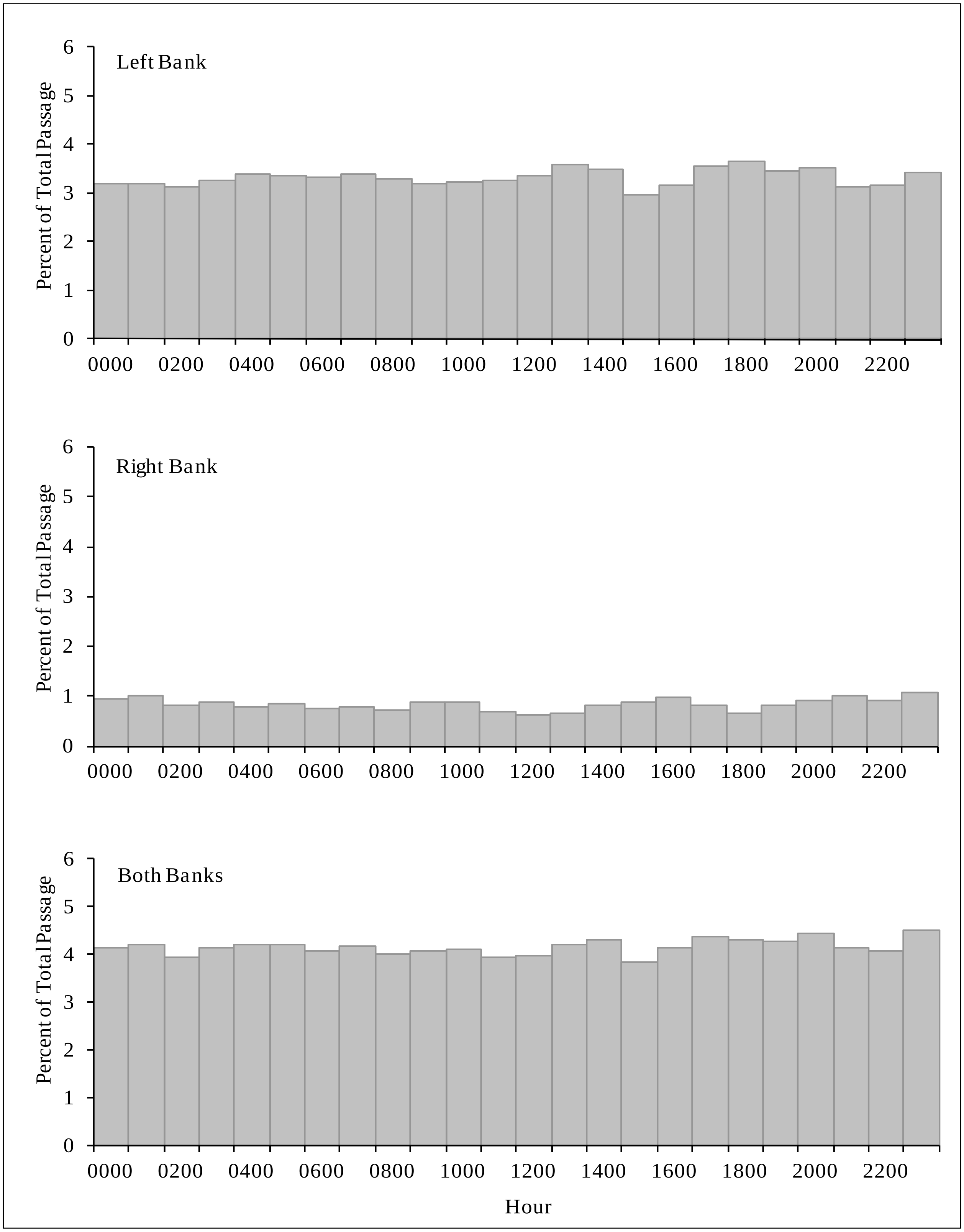


Figure 9.–Hourly Chinook salmon passage observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from July 5 through August 12, 2011.

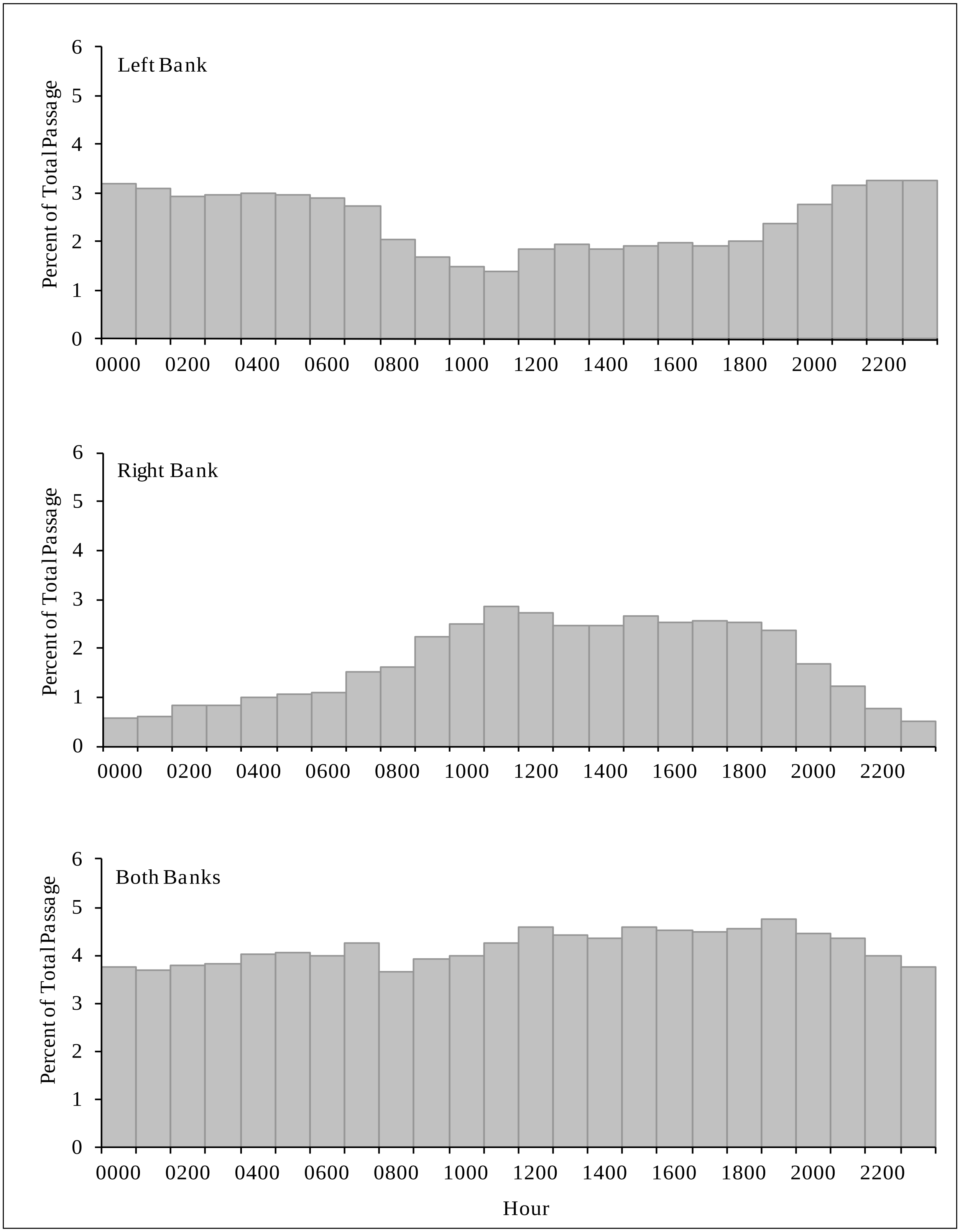
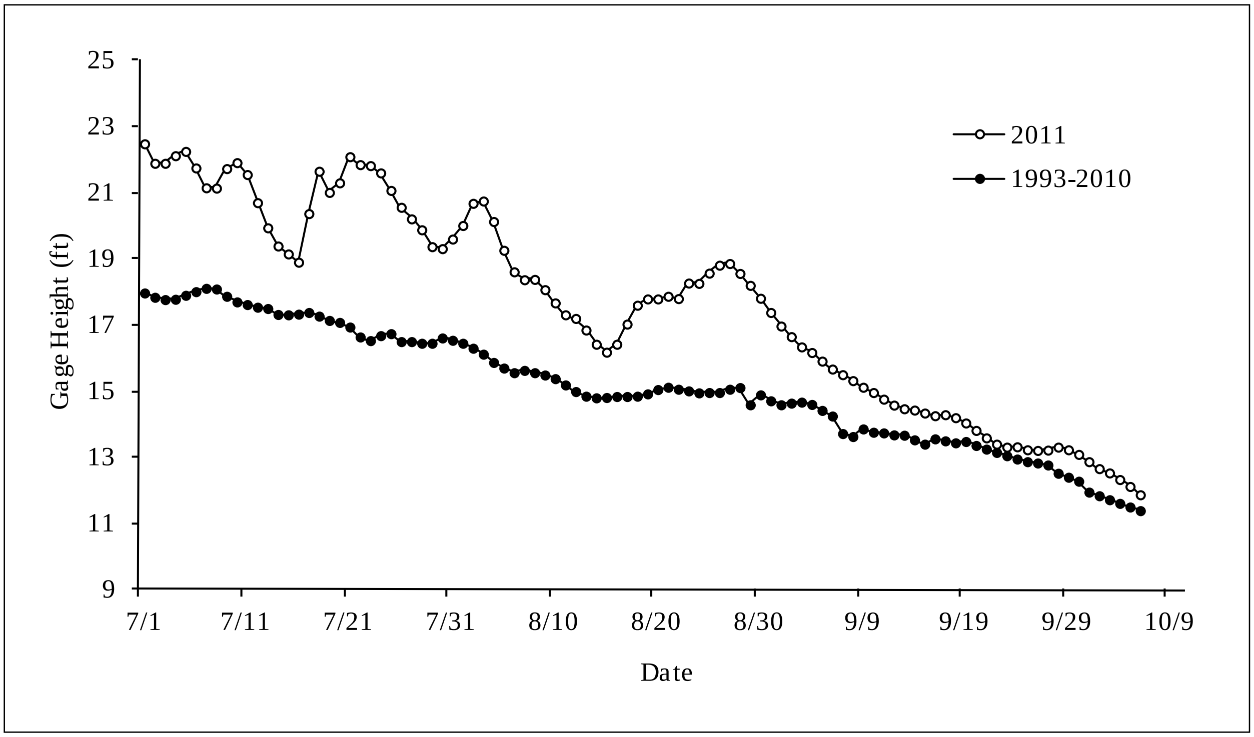


Figure 10.–Hourly chum salmon passage observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from August 13 through October 6, 2011.



Source: United States Geological Survey

Figure 11.–Mean gage height measured at Eagle, July 1 through October 6, 2011, and historic mean 1993 through 2010.

APPENDIX A. CLIMATE AND HYDROLOGIC OBSERVATIONS

Appendix A1.–Climate and hydrologic observations recorded daily at 1800 hours at the Eagle sonar project site, 2011.

	Precipitation	Wind		Sky	Temperature (C°)	
Date	(code)[a]	Direction	Speed (mph)	(code)[b]	Air	Water[c]
7/5	A	N	3	B	26.0	13.0
7/6	B	W	6	B	21.2	15.0
7/7	B	E	4	B	23.3	15.0
7/8	A	E	2	O	21.9	15.0
7/9	B	E	6	B	19.0	15.0
7/10	B	W	2	B	20.5	15.0
7/11	A	E	6	S	28.7	15.0
7/12	B	E	10	O	18.0	15.5
7/13	B	E	8	O	19.0	16.0
7/14	A	E	14	O	17.0	15.5
7/15	A	W	4	O	20.0	16.0
7/16	C	W	5	O	13.0	15.0
7/17	A	W	3	S	20.0	16.0
7/18	C	W	2	O	13.0	15.0
7/19	B	N	4	O	15.0	14.0
7/20	A	N	1	S	21.0	15.0
7/21	A	0	calm	S	19.0	15.0
7/22	A	N	6	S	24.0	15.0
7/23	A	S	7	S	25.0	16.0
7/24	A	S	8	S	21.0	16.0
7/25	B	N	2	O	15.0	16.0
7/26	B	S	5	B	18.0	16.0
7/27	B	S	1	O	17.0	16.0
7/28	A	N	9	B	20.0	16.0
7/29	A	N	8	S	21.0	17.0
7/30	A	N	8	B	20.0	16.5
7/31	B	N	1	O	14.5	15.0
8/1	A	S	16	B	20.0	14.5
8/2	A	S	10	S	19.0	14.0
8/3	A	S	8	B	21.0	15.0
8/4	A	S	16	C	21.0	15.0
8/5	B	N	4	O	15.0	14.0
8/6	A	N	2	C	15.0	16.0
8/7	A	W	4	C	17.0	15.0
8/8	A	N	5	S	15.0	13.0
8/9	B	calm	calm	B	ND	15.0
8/10	B	N	8	O	11.5	14.0
8/11	B	N	5	B	13.3	14.0
8/12	A	N	4	S	14.0	12.0
8/13	B	W	3	B	14.0	13.0
8/14	B	N	3	B	16.0	14.0
8/15	A	W	12	O	17.0	14.0
8/16	A	E	4	B	18.9	14.0
8/17	A	W	2	S	17.9	14.0

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Appendix A1.–Page 2 of 3.

Date	Precipitation (code)[a]	Wind Direction	Wind Speed (mph)	Sky (code)[b]	Temperature (C°) Air	Temperature (C°) Water[c]
8/18	A	W	3	B	20.4	14.0
8/19	A	W	6	B	21.5	16.0
8/20	B	W	6	B	18.0	14.0
8/21	B	W	3	B	16.5	15.0
8/22	B	W	1	O	15.2	14.0
8/23	B	calm	calm	S	15.0	13.0
8/24	B	N	3	B	13.1	13.0
8/25	A	NE	1	B	12.5	13.0
8/26	B	S	2	O	12.0	12.5
8/27	B	S	2	C	19.5	12.5
8/28	A	calm	calm	C	18.5	12.0
8/29	A	N	2.2	S	17.0	13.0
8/30	A	calm	calm	C	18.0	13.0
8/31	A	calm	calm	S	18.0	12.0
9/1	A	N	5	S	14.0	12.0
9/2	A	S	8	B	12.0	11.0
9/3	B	calm	calm	B	14.0	12.5
9/4	A	S	3	S	14.5	11.5
9/5	A	S	5	B	15.0	11.0
9/6	A	S	13	B	15.0	11.0
9/7	A	S	6	B	16.0	11.0
9/8	A	S	2	B	15.5	11.0
9/9	A	calm	calm	B	14.0	11.0
9/10	A	NW	4	O	9.0	10.0
9/11	A	N	3	S	11.0	10.0
9/12	A	N	4	S	19.0	10.0
9/13	A	N	6	C	20.8	10.0
9/14	A	S	4	B	20.0	11.0
9/15	A	N	2	B	13.0	10.0
9/16	A	S	1	S	8.5	9.0
9/17	A	S	5	B	14.7	10.0
9/18	A	S	2	B	9.5	8.0
9/19	A	S	4	B	16.1	10.0
9/20	A	S	15	S	16.0	9.0
9/21	A	calm	calm	O	12.0	8.0
9/22	A	calm	calm	O	10.0	9.0
9/23	A	N	10	S	7.0	7.0
9/24	B	calm	calm	O	5.0	7.0
9/25	A	N	5	O	7.0	8.0
9/26	A	V	7	B	6.0	7.0
9/27	E	N	2	O	3.0	6.0

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Appendix A1.–Page 3 of 3.

Date	Precipitation (code)[a]	Wind Direction	Wind Speed (mph)	Sky (code)[b]	Temperature (C°) Air	Temperature (C°) Water[c]
9/28	A	N	1	S	5.0	7.0
9/29	A	calm	calm	B	3.0	6.0
9/30	A	calm	calm	O	3.0	6.0
10/1	A	S	5	O	6.0	5.0
10/2	A	S	8	O	8.0	5.0
10/3	A	S	2	S	6.0	5.0
10/4	A	calm	calm	O	3.0	4.0
10/5	A	S	12	S	7.0	4.0
10/6	A	S	5	S	6.0	3.0
Average					15.2	12.2

Note: ND = no data.

[a] Precipitation code for the preceding 24 h period: A = none; B = intermittent rain; C = continuous rain; D = snow and rain mixed; E = light snowfall; F = continuous snowfall; G = thunderstorm w/ or w/o precipitation.

[b] Instantaneous cloud cover code: C = clear, cloud cover < 10% of sky; S = cloud cover < 60% of sky; B = cloud cover 60–90% of sky; O = overcast (100%); F = fog, thick haze or smoke.

[c] Water temperature collected approximately 30 cm below surface with pocket thermometer.